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RESEARCH ARTICLE

Design support tools to sustain climate change adaptation at the local level: A review and reflection on their suitability

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Abstract
For mid-latitude cities, higher summer temperatures due to climate change are a cause for concern because they aggravate the urban heat island phenomenon and reduce thermal comfort inside buildings. By acquiring the appropriate knowledge and skills, architects and urban designers can become key actors in adaptation to climate change. Two workshops bringing together architects and urban designers provided evidence of deficiencies in this area. We hypothesize that a design support tool (DST) focused on the issue of adaptation of mid-latitude cities to rising summer temperatures could help improve knowledge and skills of professionals in the field. The first section presents the results taken from a review and classification of DSTs, which highlight the tools' features that are likely to reach this goal. Tools of the "hybrid" category seem most appropriate. To verify this, seven DSTs were selected and tested by fourteen students enrolled in a graduate-level architecture design studio. The second section presents the results from this test, including an analysis of the final projects, a web-based questionnaire and two focus groups. The relevance of hybrid approaches is established, but the results bring into question the capacity of a single DST to meet the individual and multiple needs of professionals.

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1. Introduction

Global warming is undoubtedly real and the very likely increase in the frequency of heat waves (GIEC, 2007) is one of the chief concerns facing mid-latitude cities. The principal effects of summer temperature increases are to heighten the urban heat island phenomenon and to reduce interior thermal comfort in buildings. Assuming a significant rise in summer temperatures, the populations of mid-latitude cities would be more greatly affected as they are not acclimatized to extreme heat (Braga et al., 2001),

Architects and urban designers represent pivotal actors in climate change adaptation. At the urban scale, their decisions can create comfortable microclimates or, on the contrary, can contribute to urban heat island (UHI) formation. Moreover, architectural elements can determine whether a building offers passively comfortable internal spaces. However, these professionals continue to perceive adaptation as an element to be taken into account "later", in the future (Wheeler, 2008). We argue that these professionals have the following "four catalysts for action" at their disposal to strengthen the capacity of adapting the built environment of mid-latitude cities to higher summer temperatures: urban form, natural cover, architecture, and coating materials.

International students and Canadian architecture and urban design professionals working in the Québec City metropolitan context (province of Québec, Canada) participated in two workshops where it was found that they actually have only partial knowledge of the UHI phenomenon and of the passive cooling principles (Dubois et al., 2012). This appears paradoxical considering the substantial and rapidly developing body of scientific literature available today. The issue lies with its transfer to professionals and not with the production of scientific literature per se. First, the profusion of specialized knowledge can be overwhelming for these lay professionals. Second, the methods, tools and terminology used by researchers are alien to them. Third, the problem-solving procedure is fundamentally different from the traditional scientific approach. As architects and urban designers, they must be prepared to deal with "wicked" problems (Rittel and Webber, 1973). These problems require a prospective approach: in order to develop a further understanding of the problem and search for potential solutions, decisions must be taken, experiments must be conducted, pilot studies must be carried-out, and prototypes must be tested (Conklin, 2005). Thus, "wicked" problems foster new knowledge and creativity.

We hypothesize that a design support tool (DST) focused on the issue of adaptation of mid-latitude cities to rising summer temperatures could help improve knowledge and skills of professionals in the field. DSTs can facilitate designers' understanding by transferring appropriate multidisciplinary knowledge that is derived from the popularization of technical or scientific insight. Such tools apply mainly during the upstream phases of any project, when decisions on the various urban, architectural and technical options are taken and when the information available to the designer is limited (Adolphe, 1995). They can also suggest orientations, indicate trends or compare solutions according to their performance (Fernandez, 2010).

The first section of this article presents a review and classification of DSTs to describe the intrinsic qualities that can likely help improve knowledge and skills of architects and urban designers regarding climate change adaptation measures. A series of DSTs are identified at the end of this first step. They were tested during a Laval University (Québec, Canada) architecture design workshop. The second section presents the results from a field survey. The purpose of the survey was to get students to experiment with various tools used for the design of an architectural project, and ask them afterwards to validate the identified positive elements in order to better define their needs.

2. Methodology

2.1. Review

The review seeks to highlight the main features of DSTs to establish which ones are likely to improve the climate change adaptation knowledge and skills of architects and urban designers working in cold mid-latitude cities. With this intention, we propose the following two sub-hypotheses:

(1) Improving the knowledge of designers depends on tools that allow them to better grasp an issue and identify potential solutions.
(2) Improving the skills of designers depends on tools that allow them to assess the performance of the selected solutions.

The features of various DSTs that were identified are highlighted by grouping them according to the classification proposed by Chaabouni et al. (2009). Five categories are considered: the tools based on (1) "intentions", (2) "references", (3) "knowledge", (4) "performance" and (5) "hybrids". Finally, given the purpose of the research, most of the tools that were reviewed and classified (Table 1) examine one of the following issues: climate change adaptation, urban heat Island (UHI) mitigation or passive design strategies.

2.1.1. Tools based on "intentions"

The first category combines the tools based on "intentions". The intention is to express, in its conceptual form, a constraint that is imposed or not, but influencing the geometry of a project (Faucher and Nivet, 2000). These numerical simulation tools use inverse simulation to identify solutions able to satisfy the designer's desired effect (or intention). The intention type tools include the SVR (Houpert, 2003), SOLIMAC (Siret, 1997) and DE VISU (Nivet, 1999) software prototypes along with the inverse simulation model of daylighting (Tourre, 2007). None of them have been applied beyond the experimental prototype, since they were developed in the context of doctoral research.

Tools based on "intentions" such as the inverse simulation model of daylighting (Tourre, 2007) are very specialized. It has the ability to predict how daylight is distributed within a given space and to compare it with the intention of creating a particular ambience. More specifically, the model estimates the geometrical and photometric properties of the openings needed to achieve the intended lighting effect. The inverse simulation model is very precise, but is strictly limited to daylighting effects. It is incapable of taking several criteria simultaneously into account, because

Table 1 Design support tools reviewed and classified.

Category	Objective	Tools
Intentions	To identify solutions able to satisfy the designer's desired effect (or intention).	• SVR software (prototype) (Houpert, 2003). • SOLIMAC software (prototype) (Siret, 1997). • DE VISU software (prototype) (Nivet, 1999). • Inverse simulation model of daylighting (prototype) (Tourre, 2007).
References	To reflect, characterize and compose effects by manipulating photographic reference images.	• MaTerre'iO software (prototype) (Fernandez, 2010). • DILEM'Matériaux software (prototype) (Tornay, 2011). • KALEIDOSCOPE software (prototype) (Scaletsky, 2003). • Daylight Design Variations Book website (TNO-TUE Centre for Building Research, 2000).
Knowledge	To provide knowledge and references on specific issues in order to select a solution.	• Climate change adaptation by design: a guide for sustainable communities (Shaw et al., 2007). • Urban Climatic Map and Standards for Wind Environment (School of Architecture CUHK, 2011). • Reducing UHI: Compendium of Strategies (US EPA, 2008).
Performance	To provide an assessment of the performance of solutions proposed by designers by drawing on quantifiable indicators.	**Simplified computation tools** • Local Climate Zone (indicators) (Stewart, 2011). • LUMcalcul v2.08 (Demers and Potvin, 2004). • PET v5.1 (Potvin et al., 2004). **Analogical simulation tools** • Mirror-box type of artificial sky (GRAP, 2010a). • Heliodon (GRAP, 2010b). **Numerical simulation tools** • ENVI-Met 3 software (Bruse, 2010). • Integrated Environmental Solutions (IES)© software. • Autodesk Ecotect Analysis© software.
Hybrids	To reflect, to select and to assess the performance of a solution.	• Sun, Wind & Light - Architectural Design Strategies (Brown and DeKay, 2000). • The Green Workshop Handbook: Environmental Strategies for Schematic Design (Kwok and Grondzik, 2011).

otherwise it would generate an excessive number of potential solutions (Chaabouni et al., 2009). In addition, its operation implies that the designer has mastered a body of knowledge about daylighting. Otherwise, it would be difficult to formulate a realistic plan for a luminous lighting atmosphere even before using the tool. The designer is unable to use the tool to explore other potential solutions and to compare them because the geometric and photometric properties that are produced are considered optimal with respect to the initial intentions.

2.1.2. Tools based on "references"

The tools based on "references" help the designer to reflect, characterize and compose effects (luminous, tectonic, constructive, etc.) by manipulating photographic reference images. These methods are adapted to the designer's needs at the initial draft stage when the project is not yet well defined as they allow the designer to explore several potential solutions. The MaTerre'iO (Fernandez, 2010), DILEM'MAtériaux (Tornay, 2011) and KALEIDOSCOPE (Scaletsky, 2003) software prototypes along with the "*Daylight Design Variations Book*" (TNO-TUE Centre for Building Research, 2000) website are part of this category (Table 1). The latter is also an exception in that it provides a breakthrough and is of particular interest to one of the issues raised in our research.

Indeed, the "*Daylight Design Variations Book*" website allows the designer (1) to examine various types of openings, (2) to compare two types according to performance indicators and (3) to associate each type to architectural precedents (TNO-TUE Centre for Building Research, 2000). The tool thus improves the designer's understanding of potential solutions with regards to daylighting. However, it does not foster a better understanding of the passive strategy. This situation is illustrative of tools based on "references". The images are the dominant feature, both for navigation and for presenting comparative results or reference buildings, but the textual information is kept to a minimum.

2.1.3. Tools based on "knowledge"

Design support tools based on "knowledge", as their name implies, are specifically aimed at instruction and knowledge acquisition. They generally appear as guides proposing both textual information and visual references. The documents "*Climate Change Adaptation by Design: A Guide for Sustainable Communities*" (Shaw et al., 2007), "*Urban Climatic Map and Standards for Wind Environment*" (School of Architecture CUHK, 2011) and "*Reducing UHI: Compendium of Strategies*" (US EPA, 2008) belong to this category (Table 1).

The principle on which rests the tools based on "knowledge" is exemplified in the work "*Urban Climatic Map and Standards for Wind Environment*" (School of Architecture CUHK, 2011). The clear, synthetic and graphic information found in the guide improve the knowledge of designers working in Hong Kong with regards to UHI mitigation strategies. The guide provides a series of planning recommendations that vary according to the city's different microclimates. The recommendations emphasize urban and architectural measures for promoting ventilation of the urban fabric, which are most effective in increasing the thermal comfort of citizens of this city characterized by a humid subtropical climate. However, similarly to tools found in the "intentions" category, the performance of the selected mitigation measures can not be verified. The designer must rely on the recommendations made by the guide's scholarly authors. For this reason, the guide does not improve the skills of designers, just as the bulk of tools based on "knowledge".

2.1.4. Tools based on "performance"

Tools based on "performance" provide an assessment of the performance of solutions proposed by designers by drawing on quantifiable indicators. Depending on the time invested, the medium and the desired degree of accuracy, several opportunities are available: simplified computation tools, analogical simulation tools and numerical simulation tools (Table 1).

Simplified computation tools allow the designer to quickly compare design assumptions without the need to master all of the knowledge needed to operate the tool nor to begin by conceiving a detailed model of the project. The results take on the form of numerical values, tables or graphs. The "Local Climate Zone" (LCZ) (Stewart, 2011), the simplified computation spreadsheets "LUMcalcul v2.08" (Demers and Potvin, 2004) and "Profil d'équilibre thermique v5.1" (PET) (Potvin et al., 2004) belong to this sub-category (Table 1). Although significant comparative results can be obtained fairly easily and quickly in the initial design phases, they can also be a drawback. The results are average values unsuitable for spatializing the space under study. The designer is unable to obtain a qualitative assessment of the results, which can be an impediment.

For example, the LCZ (Stewart, 2011) spreadsheet uses only 10 indicators to define 17 classes capable of documenting and measuring the UHI. These classes represent the major urban forms and landscapes that might reasonably be encountered in cities located in various contexts. Dubois et al. (2012) developed some of these indicators as part of a study on the heat exposure of 13 different communities located in Québec City. The simplicity and speed of obtaining results from indicators are however restricted to interventions on what already exists because they require a static and well-defined frame, while the upstream phases of the design process are more dynamic.

In contrast, EXCEL spreadsheets "LUMcalcul v2.08" (Demers and Potvin, 2004) and "Thermal Equilibrium Profile v5.1" (PET) (Potvin et al., 2004) exemplify the strengths and weaknesses of simplified calculations tools that can be used on new interventions. LUMcalcul was developed to assist architects in the design of daylit spaces. PET was conceived to accompany the same professionals in designing the thermal environment of space. These simplified calculation tools foster the integration of passive architectural strategies, piecemeal, by changing numerical parameters. However, they do not produce images that allow the designer to visualize the results and assess the qualities of the projected space.

Analogical simulation tools are the second subcategory of tools based on "performance" (Table 1). They make it possible to assess the performance of certain design assumptions through an interface with a scale model of the project. This experimental parametric study allows the designer to quickly draw a variable from the model and proceed to testing it. This iterative loop can be repeated until a result or a desired effect is reached.

For example, the mirror-box type of artificial sky and the heliodon are used to simulate the lighting conditions of a space or a building directly from a scale model. The mirror box recreates the natural lighting from an overcast sky based on the CIE standard (GRAP, 2010a). As for the heliodon, it reproduces the conditions of direct sunlight at different times of the day and year (GRAP, 2010b). Unlike previous tools, the mirror box and the heliodon produce both quantitative and qualitative results that are spatialized, which is an undeniable asset for designers. However, they require a more rigorous approach (constructing the scale model, methodology, etc.) and more time. There is one exception: web-based heliodons are now integrated into all 3D modeling software. In this case, the study of cast shadows does not require the construction of a scale model nor is additional time necessary on the part of the designer.

The numerical simulation tools constitute the last subcategory (Table 1). These tools, which use 3D virtual models, enable much more extensive and comprehensive parametric studies than those in the previous subcategory. "ENVI-Met 3" (Bruse, 2010), "Integrated Environmental Solutions (IES)©", and "Autodesk Ecotect Analysis©" are software packages found in this category.

The "Autodesk Ecotect Analysis©" software serves as a good example of the strength and weaknesses of a numerical simulation tool. First, the software is compatible with many existing CAD tools. The designer can therefore create a single 3D model for the overall design of the project and carry out various simulations and analyzes. There exist a number of them, including: complete building energy audits, thermal performance, water consumption and cost evaluation, solar radiation, daylighting, as well as shadows and reflections. The reporting of results is also very diverse. Indices, summaries, graphs and diagrams are suitable for conducting quantitative analyses. Shading estimates, sunray patterns, false colors and photorealistic renderings lend themselves to qualitative analyses. Various analyses can be performed on an urban scale, especially to determine the location and the overall building lay-out. Yet, most advanced components are found at the architectural scale, principally to validate the performance of passive strategies. The handling of "Autodesk Ecotect Analysis©" requires a rather well-defined project, a great deal of time and expert users for the command, integration and the processing of data and precise knowledge on a wide range of environmental issues, which very few designers can claim. They must understand in fact the physical scales at stake and translate them into architectural choices (Fernandez, 2010). Provided they know and understand the issues in advance, the major constraints involved in most simulation tools can certainly help to improve the skills of designers.

In short, all tools based on "performance" provide the designer with various ways, ranging from the simple to the highly complex, to assess the performance of their choices and improve their skills. However, the lack of explanation or suggestion of potential solutions remains an obstacle to improving their knowledge.

2.1.5. Hybrid tools

Hybrid tools refer to a number of DSTs that have shared properties found in tools based on "references", "knowledge" and "performance". We propose to add this fifth category to the four groups identified by Chaabouni et al. (2009). The handbooks "Sun Wind & Light – Architectural Design Strategies" (Brown and DeKay, 2000) and "The Green Workshop Handbook: Environmental Strategies for Schematic Design" (Kwok and Grondzik, 2011) are considered hybrid tools (Table 1). The main strengths and weaknesses of these tools are discussed by drawing on the first manual as an example.

The handbook "Sun, Wind and Light – Architectural Design Strategies" (Brown and DeKay, 2000) is intended to provide a bridge between building science and architectural design. It contains a considerable amount of useful information and references geared towards the designer to support the different passive design strategies from the general urban scale down to the detailed level. It also offers a wide array of simplified computation methods (formulas, abacuses, etc.) that vary according to the scale and status of the project. The initial stages involve simple and quick methods while advanced stages require more complex and time-consuming methods that are also more accurate. A great deal of information, references and computation methods are contained in a 300 page manual. The designer must therefore devote considerable time to become familiar with all available information, highlight potential solutions and identify the appropriate assessment tool. This expense of time seems to contradict the purpose of DSTs.

That being said, it appears that based on the review and classification of DSTs, hybrid tools are the most likely to improve the knowledge and skills of architects and urban designers with regards to climate change adaptation, UHI mitigation and passive design strategies. In order to prove this, several of the reviewed tools were tested as part of a graduate architecture design studio[1] conducted at Université Laval (Québec, Canada).

2.2. Design support tools reviewed and tested as part of a graduate architecture design studio

2.2.1. Context

The graduate design studio entitled "physical ambiences and architectural design" examined the architectural and urban dimensions of sustainable development. The integration of various passive architectural strategies was the focal point. One professor oversaw a group of 14 students, for 6–9 h/week during a period of 15 weeks. The design studio format lent itself ideally to support the students in their learning and capacity to give shape to ideas. The design problem was never fully explained to students and few details were conveyed to them about the rules on how to proceed. Thus, they cannot assert that the "right answers" can be drawn directly from the project. They have no choice but to take risks, formalize their ideas, update their knowledge and identify priority issues for the project (Bachman, 2012; Burry, 2012). The professor taught weekly seminars as well (3 h/week) to provide students with theoretical concepts and DSTs essential for sustaining design studio projects.

Fourteen students formed into two-person teams were asked to create innovative housing complexes adapted to higher summer temperatures in Québec City, which is situated at the 46°48'N latitude and is part of the mid-latitude regions characterized by large annual temperature variations. They fluctuate on average from −17 °C in winter (in January and February) to 24 °C in summer (in July and August), but can experience extreme temperatures of −36 °C in winter and 36 °C in summer. Seasonal temperature trends for this region through 2050 forecast an increase of average temperatures varying between 2.5 °C and 3.8 °C in winter and between 1.9 °C and 3 °C in summer (Desjarlais et al., 2010).

2.2.2. Design support tools tested

The selection process of DSTs tested by students taking part in the physical ambiences design studio was based on three criteria (1) the category, (2) the learning curve and (3) accessibility. Tools from the "intentions" or "references" categories were not tested because software prototypes that could be found were still at the experimental stage, thus inaccessible (Table 1). No tests were carried out on tools solely based on "knowledge" given that the lecture course that accompanied the workshop could draw directly from the textbook "Sun Wind & Light" (Brown and DeKay, 2000). This hybrid tool assists student learning during the seminar and validates projects in the architecture design studio. Most of the tools tested thus belong to the

[1]Master's degree programme in architecture (M.Arch), School of Architecture, Université Laval, Québec City, Canada

"performance" category. Priority was given to the simplest ones, as they can quickly be used by students. Tests were conducted on the three simplified computation tools "LUMcalcul" (Demers and Potvin, 2004), "PET" (Potvin et al., 2004) and on some indicators of "LCZ" (Stewart, 2011). The same goes for analog simulation tools such as artificial sky (GRAP, 2010a) and the heliodon (GRAP, 2010b). Among numerical simulation software, which require considerable training time, only Autodesk Ecotect Analysis© was tested: Université Laval already held operating licenses and the facilitators at the design studio as well as at the seminar had sufficient training and experience using this tool to assist students in applying it. The 7 DSTs were handled by the 14 students in the design process of their residential project at various times, depending on the teams.

2.2.3. Experimental procedure

To assess the ability of selected tools to improve knowledge and skills of architecture students about strategies to promote adaptation to rising summer temperatures in cold mid-latitude cities, a three-prong survey was conducted over a six month period: (1) the analysis of the 7 projects completed over the course of the semester, (2) the results of a web-based questionnaire intended for design studio students and (3) feedback received from these students during two focus groups (Figure 1).

The architecture workshop facilitator conducted the analysis of the 7 housing complexes presented at the end of the term (April 2013). The analysis considered the written and graphic materials produced by the students for their final presentations. The evaluation framework is built around two criteria (1) the presence of evidence (written or graphic) using one of the DSTs tested and (2) the identification of the tools used (name) and their compilation (total) (Table 2).

The second step was to corroborate the results from the analysis of the final projects. Towards this end, a web-based questionnaire, created specifically for the purpose of the study, was distributed in September 2013 to the 14 students taking part in the architecture design studio (Figure 1). The survey was created and published by using the online survey platform FluidSurveys©, which was selected due to easy access (free of charge) and user-friendliness (easy to use, clear and simple presentation). The survey is composed of 2 sections and includes 16 questions. The 9 questions in the first part assess the contribution of the design studio and the accompanying seminar towards the improvement of students' knowledge on the various components related to climate change adaptation. The 7 questions in the second part assess the contribution of the tested DSTs towards project development, which is a way to improve students' skills. The survey was anonymously completed by 13 of the 14 students and the results were statistically processed.

The third and final part of the investigation involved the organization in October 2013 of two focus groups to validate and bring into sharper focus the results taken from the project assessments and the questionnaire (Figure 1). The 12 participants were split into two groups to encourage exchanges. The first group was composed of four students, while eight students took part in the second group due to schedule constraints. A person unrelated to the professor was asked to facilitate discussions in order to reduce potential bias. Topics covered in the web-based questionnaire were addressed, but they were widened in order to gain information on the following five parameters: (1) the features of tested DSTs that were appreciated, (2) the intrinsic qualities of preferred tools, (3) the means of introducing tools into the design process, (4) the professional experience gained by students and (5) their opinion on the plausibility that practitioners will use these tools when designing an architectural project. The discussions were recorded, transcribed, and a content analysis was conducted on the five parameters referred to above.

Qualitative and quantitative results of the analysis of the final projects, the web-based questionnaire and focus groups

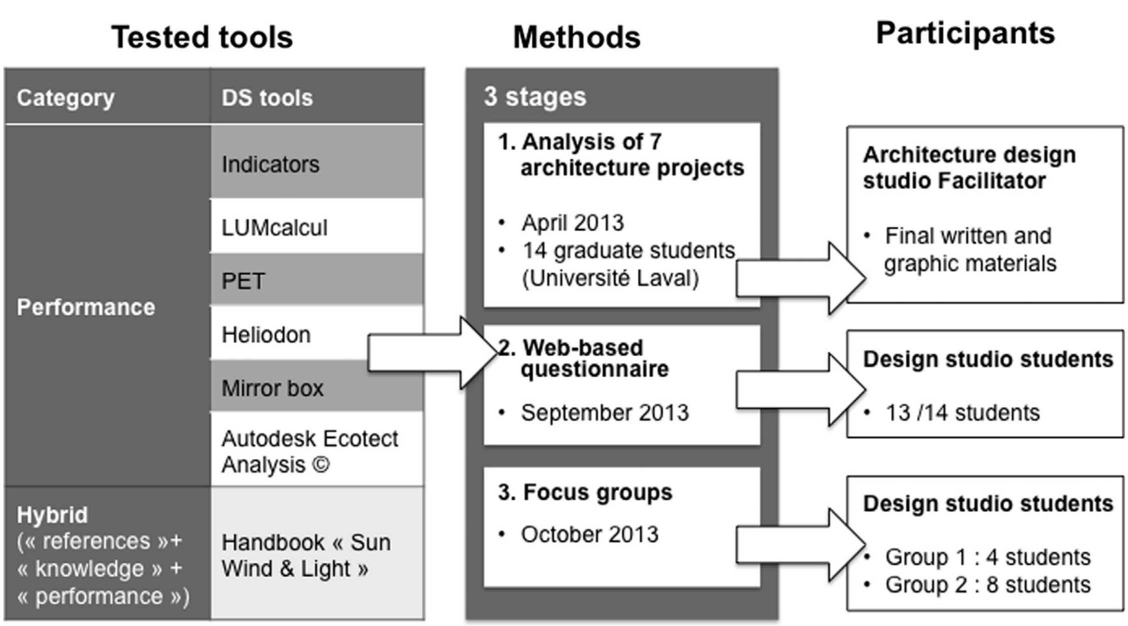

Figure 1 Experimental procedure

Table 2 Projects' evaluation framework.

Proof that a Design Support Tool (DST) has been used in the Students Final Presentations		**Project**							**Total (/7)**
		1	**2**	**3**	**4**	**5**	**6**	**7**	
Indicators	Built, pervious and impervious surface fraction diagram (%)		1	1	1		1	1	**5**
	Land use distribution diagram (residential, commercial, institutional, etc.) (%)			1	1		1	1	**4**
	Dwelling net density (u./ha.)			1	1	1		1	**4**
	Tree cover fraction (%)			1	1	1		1	**4**
	Passive volume (%)			1		1		1	**3**
	Built density (u.)					1		1	**2**
	Compacity coefficient (u.)							1	**1**
Heliodon	Photo renderings – sunlight patterns			1					**1**
Sketchup	Section drawings – study of cast shadows	1	1	1	1	1	1	1	**7**
	Plan drawings – study of cast shadows							1	**1**
Ecotect	Display shadows	1		1	1	1			**4**
	False colors renderings – sunlight exposure		1		1	1	1		**4**
	False colors renderings – daily shadow patterns	1				1			**2**
	False colors renderings – wind speed		1						**1**
Total (/15)		**3**	**4**	**8**	**7**	**8**	**4**	**9**	

are presented in the next section. Their purpose is to assess the hybrid DSTs by focusing on the features that are likely to improve knowledge and skills of architects in matters relating to climate change adaptation.

3. Results and discussion

Results are presented in a way that combines tools with similar features (category, project status) or dealing with similar issues (UHI mitigation or passive architectural strategies. First, results are discussed on the use of the manual "Sun Wind and Light" (Brown and DeKay, 2000) as a hybrid DST in relation to the simplified computation tools "PET" (Potvin et al., 2004) and "LUMcalcul" (Demers and Potvin, 2004). These three tools are tailored to the initial design phases and address one or more passive architectural strategies. Second, the results of the integration of indicators in the workshop project are discussed separately as they concern essentially the urban scale, which is not the case with previous tools. Third, the appraisal of the use of the numerical simulation software Ecotect Autodesk Analysis© is examined by comparing it to the analogical simulation tools "mirror box" and the heliodon. These three tools based on "performance" are more suitable for the more advanced stages of the design process, and deal with some or all passive architectural strategies.

3.1. Sun Wind & Light, LUMcalcul and PET

The handbook "Sun Wind & Light" (Brown and DeKay, 2000) contains several simplified computation methods that can be compared to the simplified computation spreadsheets "LUMcalcul" (Demers and Potvin, 2004) and "PET" (Potvin et al., 2004). Analysis of written and graphic materials presented in the final proposals does not clearly establish the contribution of these tools towards the design of projects.

Results from the questionnaire confirm on the contrary that to design their project, teams drew a lot more on the empirical formulas and abacuses provided in the handbook. The following question was asked: "do you feel that the Sun, Wind and Light tool was useful for you in developing your project in the course of the design workshop?" In all, 5 out of 13 students found it "extremely useful", 4 "very useful", and 4 "rather useful". In contrast, although "LUMcalcul" and "PET" are both simplified computation tools, they were less appreciated by students. In the first case, 1 student found the worksheets "extremely useful", 3 "very useful", 5 "rather useful" and 4 "barely useful". Comments received by students during both focus groups help understand that the manual's integrated and comprehensive approach makes it easier and more efficient to use than the two other tools.

"Sun, Wind & Light" was valued for its hybrid nature. Students reported being inspired by the numerous clear-cut and pragmatic architectural solutions deployed at the urban, architectural and detail scales (tool based on "references"). They expressed disappointment, however, that few urban and architectural precedents adapted to cold mid-latitudes were provided. They appreciated the educational focus of the handbook, which offered them several opportunities to learn about and understand the phenomena (tool based on "knowledge"). "LUMcalcul" and "PET" were not associated with such benefits. The handbook was considered easy to use and effective, given that it does not involve entering a lot of data or modeling the entire space in order to rapidly obtain an answer (tool based on "performance"). As for abacuses, the majority found them tremendously effective, while others were unable to use them without assistance.

These comments suggest that "LUMcalcul" and "PET" are DSTs that are further away from the architectural project. Their operation, based on numerical values, was not easily understood by the responding students. They were afraid of making errors while trying to translate design hypotheses into quantifiable parameters and to interpret results. Besides, one of the participants was unable to confirm whether the results were genuine since they cannot be translated into pragmatic architectural solutions. In contrast, “Sun Wind & Light” is very close to the urban and architectural reality.

In view of the results from the survey and the numerous positive comments recorded during both focus groups, we can assert that the hybrid nature (“references” + “knowledge” + “performance”) of a tool such as the handbook “Sun, Wind and Light” is more conducive to improving knowledge and skills of architecture students than the tools based on “performance” of the “simplified computation tools” subcategory.

3.2. Simplified computation tools - the indicators

Some indicators applied by Dubois et al. (2012) to assess the degree of exposure to heat in different communities of Québec City were presented to the students in order to assess whether their project could mitigate the UHI effect and support passive architectural strategies. All 9 indicators were written down on posters on permanent display in the design studio.

Findings from the analysis of the projects handed in at the end of the semester showed that 6 teams out of 7 integrated some “indicators” (Table 2). That being said, only the simplest indicators (dwelling net density [u./ha] and tree cover fraction [%]) or those that can be represented graphically (Built, pervious and impervious surface fraction diagram [%], land use distribution diagram [%]) (Figure 2) were incorporated in the presentations given by over half of the teams (Table 2).

The results emerging from the web-based questionnaire pointed as well to the ambivalence felt by students towards indicators used as a DST. Students were asked the following question: “using the scale provided, how would you rate the utility of the presentation and the estimation method of indicators in developing your project in the course of the workshop?” Out of the 13 students, 1 considered them “extremely useful”, 5 “very useful”, 6 “rather useful” and 1 “barely useful”. Statements made by some of the students taking part in the focus groups were less ambiguous. They asserted not having estimated indicators to evaluate the performance of their project during the design phase, but rather to take advantage of the communicational quality of these tools: “in my view, indicators provided members of the jury with an overview of every project, which made it possible for them to draw comparisons between the various proposals” (respondent, group 2). It was noticeably clear that “indicators” served as a tool for communicating results, instead of supporting the design process.

3.3. Analogical and numerical simulation tools

The software Autodesk Ecotect Analysis© offers many features to assess the performance of daylighting and passive solar heating. The mirror box type of artificial sky (GRAP, 2010a) and the heliodon (GRAP, 2010b), two analogical simulation tools, do the same. SketchUp Pro 2013© is a CAD software used by students to model and present their project design. It also allows them to study the cast shadows on their 3D model like the analogical heliodon.

Findings from the analysis of the proposed housing complexes confirm that 6 teams out of 7 made use of one of the Ecotect Analysis© applications to assess the performance of the proposed solutions (Table 2). In contrast, while only one presentation addressed the contribution of the analogical helidodon towards the development of the project, none addressed the contribution of the mirror box type of artificial sky. However, all projects without exception proposed drawings in which cast shadows were shown as simulated by the software SketchUp Pro 2013©. The execution stage of the final projects was a factor that may have contributed to the wide use of the Ecotect Analysis©, which can only be applied during the advanced design stage.

The results of the web-base questionnaire enabled us to conclude that the features of the Autodesk Ecotect Analysis© software were well appreciated by architecture students and allowed them to improve their skills. The following question was asked: “do you feel that the Autodesk Ecotect Analysis© software was useful for you in developing your project in the course of the design studios?” In all, 10 out of the 13 students found it “extremely useful” or “very useful”.

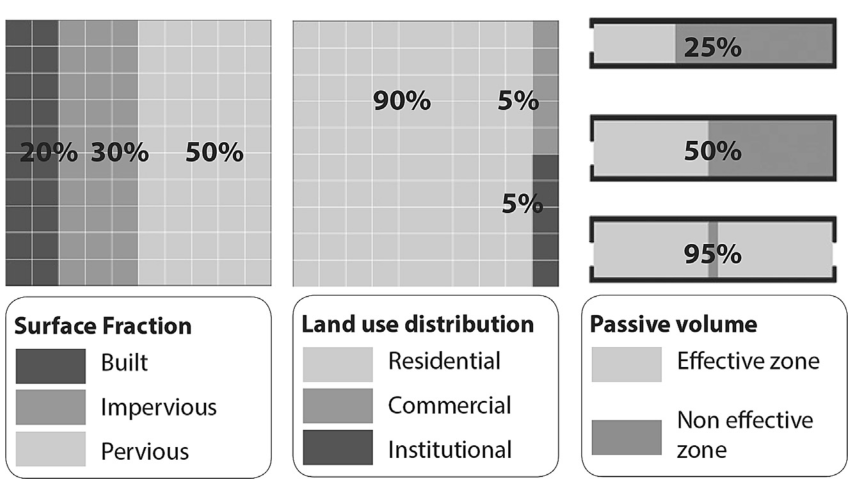

Figure 2 Indicators that may be represented graphically.

However, the results are less conclusive for the analog simulation tools. In this respect, students considered the mirror box type of artificial sky and the heliodon less helpful: 6 considered them “rather useful” and 1 “barely useful”. We were able to gain a deeper understanding of these results from the statements made by some of the students during both focus groups.

The Autodesk Ecotect Analysis© software was highly valued by students for its capacity to fully validate the project's performance and thereby help justify the conceptual choices. It fits easily within the design process; students are accustomed to building a virtual scale model of their project. In contrast, it is clear from focus groups that the time required to build a real scale model, mandatory to use the mirror box or the heliodon is not justified by the precision of the results. The architect has to momentarily interrupt the design process in order to use these analogical tools, which is seen as an irrelevant interruption. It follows that the creation of a virtual scale model is pursued on a more fluid and continuous basis. In addition, although it requires a considerable amount of time to build, the interest in the virtual scale model lies in the fact that it can be used during several stages (design, validation, presentation, etc.). However, for a number of students, the time needed to properly operate the software acted as a barrier. Some called into question the validity of the results obtained, and admitted not having a firm command of all the software parameters. However, given that all projects developed in the course of the architecture workshop included software analysis, that the results of the survey clearly demonstrated its utility and that the majority of statements recorded during focus groups were positive, it is reasonable to say that the Autodesk Ecotect Analysis© software has several features that improve the skills of students. Yet, since the software does not provide any information about the phenomena under study, they must already have acquired a fairly high level of knowledge to be able to gain any benefits.

3.4. Discussion

Although students indicated preferences for some of the tools, none were considered “useless”. They asserted that every tool examined during the seminar and the architecture design studio could offer them support, either on an ongoing or a needs only basis, in the development of their project. The following comment summarizes well the overall statements expressed during focus groups with regards to the qualities valued in a tool:

> “I believe that the proposed tools were relevant. Deciding to apply a tool or not depended on its user-friendliness and the time required to figure out how it works. With the time at our disposal during a short semester, quickly mastering a tool is a logical reason to choose it. Best effort-effect ratio” (respondent, group 2).

More specifically, students argued that every tool proved its utility during a particular project phase; they acknowledged without hesitation that a number of tools allowed them to ground their project, as well as confirm the initial design hypotheses. Another set of tools allowed them to validate project details. They considered tools to be complementary and that their use contributed to the improvement of the entire project. They appreciated the opportunity to select a DST according to (1) the preferred work method (handbook, real scale model, software, etc.), (2) the scale, (3) the design problem (UHI mitigation or passive design strategies) and (4) the design phases.

The results of the test with 14 graduate students from Université Laval indicate therefore that the valued features involve several types of tools rather than just one. In this sense, tools found in the “hybrid” category are more likely than others to improve knowledge and skills of architects and urban designers on issues such as climate change adaptation. Intrinsic qualities such as “inspirational” (usually related to tools based on “references”), “educational” (unique to tools based on “knowledge”), “simple, precise and effective” (features of tools based on “performance”) and “friendly” (relatively easy to integrate into the design process) are those sought by survey respondents who could distinguish a more comprehensive DST from others.

That said, new stages of investigation should be conducted before drawing definitive conclusions. First, the small sample size reduces the ability to generalize the results. Subsequent research should include an assessment of tool appreciation with a larger number of respondents. Second, it would be interesting to measure with greater precision the designers' interest for DSTs. Students taking part in the design studio, unlike practitioners, were required to apply selected tools to achieve the educational objectives of the design studio and this could have lead to a biased perception and use of these tools. Along similar lines, the academic context of the study has its own limitations (due dates, evaluation criteria, DST learning curve versus semester duration, etc.), which differ from those found in professional practice. This represents a third limit. Learning conditions are indeed different: those in the university setting usually involve resources that are absent in practice setting (timeframes, professors, equipment, etc.).

In contrast, the context of an architecture workshop offers undeniable advantages to conduct a three prong investigation such as ours (testing tools, survey and focus groups). Once 7 DSTs were identified, they could be tested under the same conditions, while this would not be possible in a professional context. Student availability, six months after the end of the architecture design studio, also allowed us to obtain more precise information on the features of experimented DSTs.

Moreover, despite these limitations, we argue that the results presented, which focus on the potential intrinsic qualities of tools that can improve the knowledge and skills of architects and urban designers on issues such as climate change adaptation, are transferable to professionals. Project design is a process of solving particular problems common to students and professionals.

4. Conclusion

Higher summer temperatures due to climate change are a cause for concern for mid-latitude cities because they aggravate the UHI phenomenon and reduce interior thermal comfort in buildings. Architects and urban designers are key actors in implementing particular climate change adaptation measures. Their decisions, taken either at the urban or at the building scale, can be effective in reducing the UHI effect or improve a building's passive cooling capacity. The success of adaptation measures depends however on the knowledge and skills of professionals. The scientific literature on the issue of climate change adaptation is abundant and recent, but it is difficult to transpose it to the practice of architecture and urban design. We assumed that a DST centered on this issue could help improve knowledge and skills of professionals in the field, because they can link design to science.

This article initially presented a review and a classification of existing DSTs, which showed that the features of tools based on "references" and "knowledge" did in fact improve the knowledge of designers since they provided them with a clearer understanding of an issue ("knowledge") and a way to identify potential solutions ("references"). Regarding skill improvement, tools based on "performance" seemed the most effective because they helped designers objectively assess the proposed solutions. In this context, hybrid tools, which share common characteristics found in the three categories mentioned above, have emerged as being particularly suited to the needs of designers.

Second, results were presented of a test with 14 students participating in a graduate architecture workshop. The workshop served as a venue to evaluate the capacity of 7 targeted tools to demonstrate whether the inherent features of the hybrid tools made them more likely to improve the knowledge and skills of designers. The tools were tested by students while they were designing a residential complex that had to be adapted to the actual and future climate of Québec City, a region located in the cold mid-latitudes. The findings from the analysis of 7 projects developed during the semester, combined to the results of a web-based questionnaire and two focus groups highlighted the utility of DSTs and confirmed the relevance of hybrid approaches. Designers actually appreciated the tools that they found to be:

- Inspirational
- Educational
- User-friendly
- Simple
- Efficient
- Precise

These findings also shed new light on the real needs of architects and urban designers during the design process. They prefer selecting DSTs by considering:

- The preferred working method.
- The scale.
- The design problem to be solved.
- The status of the project.

This evidence seems irreconcilable with the idea that a single DST, even if focused specifically on the issue of climate change adaptation, could be able to meet their individual and multiple needs. Creating a roadmap for architects and urban designers is an idea worthy of further exploration. It could assist them in steering a course between various sources of information, references and existing DSTs to improve their knowledge and skills relative to climate change adaptation, while allowing them the freedom to choose and create.

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